NAVAL AIR DEVELOPMENT CENTER

Warminster, Pennsylvania

NADC-CS-7135

30 December 1971

FLASHBLINDNESS RECOVERY FOLLOWING EXPOSURE TO CONSTANT ENERGY ADAPTIVE FLASHES

Naval Air Systems Command
AirTask WF00523-401
Work Unit No. 2

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29

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Crew Systems Department Naval Air Development Center Warminster, Pa. 18974	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

FLASHBLINDNESS RECOVERY FOLLOWING EXPOSURE TO CONSTANT ENERGY ADAPTIVE FLASHES

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Interim Report

5. AUTHOR(S) (First name, middle initial, last name)

Gloria T. Chisum

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
30 December 1971	21	4

8a. CONTRACT OR GRANT NO. b. PROJECT NO. AirTask WF00523-401, Work Unit No. 3 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NADC-CS-7135 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Air Systems Command Department of the Navy Washington, D.C. 20360

13. ABSTRACT

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DD FORM 1 NOV 65 1473 (PAGE 1)

0014 6600

Unclassified
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. Flashblindness						
2. I-t Reciprocity						
3. Block's Law						
4. Bunsen-Roscoe Law						

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Flashblindness Recovery Following Exposure To Constant Energy Adaptive Flashes

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AirTask WF00523-401
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SUMMARY

Times required to detect a simple display were measured following exposure to adapting flashes of different durations but equal integrated luminances. The results indicate no consistent variation in response times as a function of flash duration when the total integrated luminance of the flash is constant. The variations which do occur are interpreted as indicating that a strict reciprocity relationship does not apply at very short adapting flash durations.

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INTRODUCTION

The occurrence of an unanticipated intense flash of light in the visual field will result in some visual exposure even though a protection device may be worn. That exposure will temporarily reduce visual sensitivity or cause flashblindness, as that reduction in sensitivity has been called. The response times of proposed flashblindness protective devices have ranged from a few microseconds to several milliseconds. The great difficulty encountered in devising a protective device which is capable of producing densities of 3 or more within a few microseconds following the onset of a high intensity light flash warrants careful assessment of the relationship between the duration of a flash and the extent of visual incapacitation produced. Data reported several years ago (2,3) suggested that the reciprocity relationship described by Block's Law did not apply to adapting effects of flashes in the microsecond range. Block's Law stated mathematically is $L \cdot t = C$ where L is the flash intensity, t is the flash duration and C is a constant when $t \le t_C$, the critical duration (1).

In general, for effects near threshold, it has been found that the strict reciprocity relationship applies below a critical duration, the maximum of which is about 100 milliseconds. For longer durations, the relationship does not hold, and for durations longer than approximately one second, the threshold effects are independent of duration. Except for the suggestion of an adapting flash reciprocity failure at very short durations, referred to earlier, the intensity-duration reciprocity relationship described for threshold effects applies to the adapting effects of high intensity flashes.

The earlier studies (2,3) were designed to examine flash effects other than the reciprocity relationship. The suggestion in those data was that adapting effects produced by high intensity flashes shorter than one millisecond did not follow the reciprocity predictions, and that variations in duration produced variations in adapting effects even when the total integrated energy in the flashes remained constant. The present study was undertaken to examine the adapting effects of high intensity flashes of light of equal integrated luminances but different durations.

MATERIALS AND METHODS

Apparatus

A schematic diagram of the apparatus is shown in Figure 1. The adapting flash is provided by the xenon flash lamp, XL. After passing through the collecting lens, L_1, and the collimating lens, L_2, the beam is converged by L_3 at the aperture A_1. The beam is directed on to the rotating mirror shutter, RS, by the mirrors M_1 and M_2. The mirror M_3

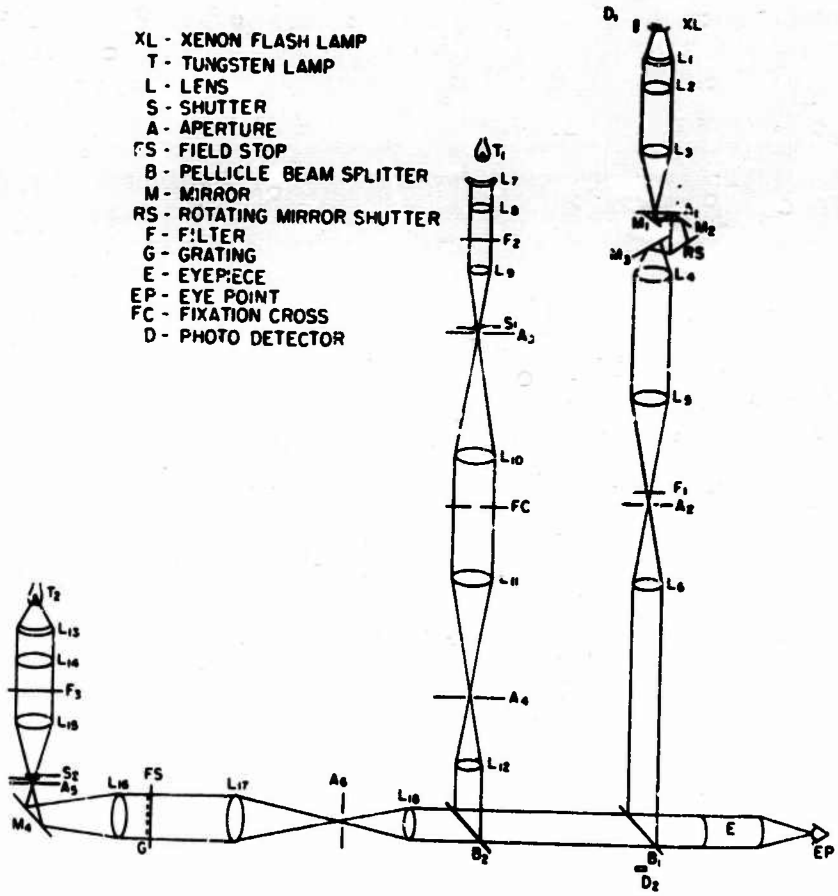

Figure 1. Apparatus schematic diagram.

directs the beam through L_4, where it is again collimated. The beam is converged by L_5 at the aperture, A_2, after passing through the filter F_1. The speed of rotation of RS which was controllable and the size of the aperture A_1 determine the duration of the adapting flash. The lens, L_6, again collimates the beam, and places an image of the area between L_4 and L_5 in front of the ocular of the system E, which was mounted in the wall of a light-tight chamber. To the eye of the observer positioned at EP by a dental impression bite plate, the last lens of the ocular is seen in Maxwellian view and appears as a sixty degree field of view when no field stop is placed between L_4 and L_5.

The gaze of the observer is directed by a small red fixation cross, FC, a clear cross on an opaque screen, transilluminated by light from a tungsten filament lamp, T_1. The chromatic composition of the light of T_1 is controlled by an interference filter, F_2, which is placed in a collimated portion of the beam between L_8 and L_9. The shutter, S_1, controls the time of presentation of the fixation cross. The beam is collimated by L_{10}, passes through the fixation cross, and is converged by L_{11} at the aperture A_4 . L_{12} again collimates the beam and places an image of FC in front of the ocular.

The visual display, or target, consists of a grating pattern, G, of parallel opaque lines separated by clear spaces equal to the lines. The grating is mounted in the system so that it can be oriented either horizontally or vertically in the view of the observer. The grating is transilluminated by light from the tungsten filament lamp T_2 which passes through the collecting lens, L_{13}, the collimating lens, L_{14}, neutral density filters, F_3, and is converged at A_5 by L_{15}. The shutter, S_2, controls the duration of presentation of the display. The mirror M_4 directs the beam through the lens L_{16} which collimates it before it passes through the grating and field stop, FS. The grating is located relative to L_{17} so that its image is seen by the observer at a distance of 22.5 inches. The one degree area subtended by the display is controlled by the field stop. The beam then passes through L_{17}, A_6 and L_{18} which are identical to L_5, A_2 and L_6. The fixation cross is positioned so that it is the center of the 60 degree area of the adapting flash, at the left edge of the display grating, and at a viewing distance of 22.5 inches which requires an accommodation of 1.75 diopters. Thus, the display grating stimulates a one degree foveal area centered 30 minutes nasal to the center of the fovea along the horizontal meridian. The pellicle beam splitters, B_1 and B_2, combine the beams entering the ocular so that the observer sees one visual field composed of a fixation cross, a display grating and an adapting flash at the proper intervals and in the proper spatial relations as shown schematically in Figure 2.

The stimulus sequencing, grating orientation, luminance variation, flash duration and data recording are controlled automatically by a programmable digital logic system shown schematically in Figure 3. The observer controls consist of a foot switch, FS, which is used to initiate a trial sequence and two response buttons, R, which are used to indicate target detection and orientation. The electro-mechanical

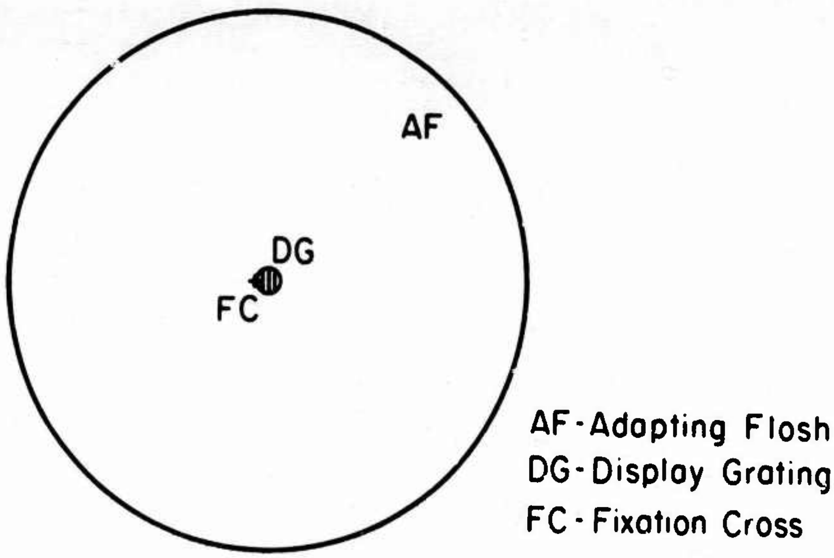

Figure 2. Schematic diagram of the visual field.

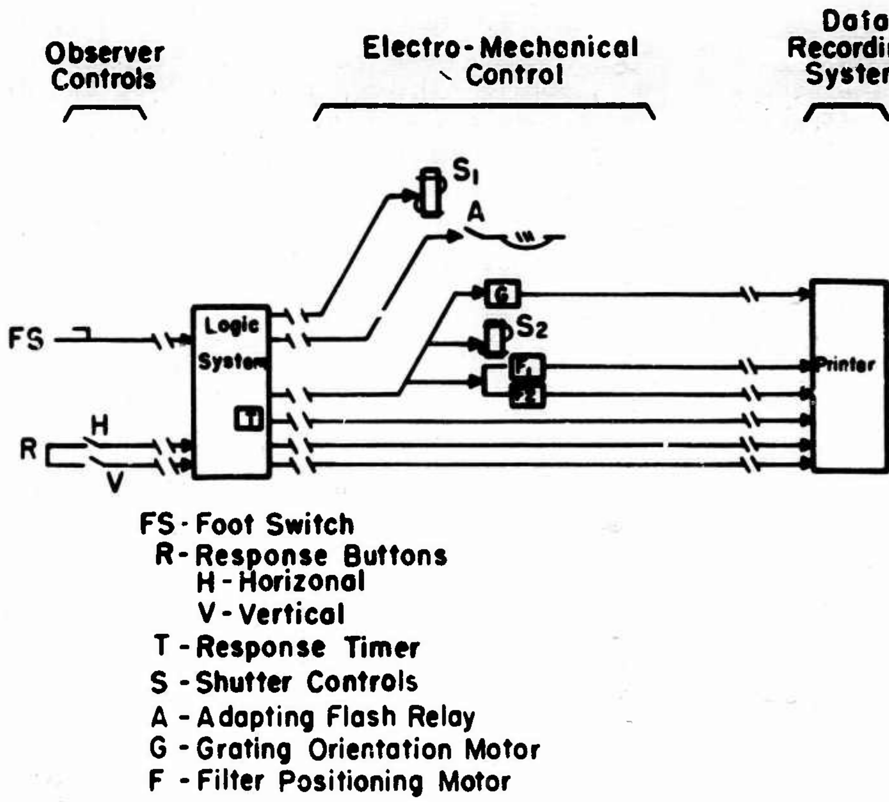

Figure 3. Stimulus control system schematic diagram.

controls consist of two shutter controls, S_1 and S_2, which effect the presentation of the fixation cross and display grating, two filter positioning motors, F_1 and F_2, for the filters which control the display luminance, a stepping motor, G, which positions the display grating in either a vertical or horizontal orientation and a relay, A, which effects the operation of the xenon flash lamp. The timer, T, provides a measure of the observer's response time. Sequencing of the operation of the electro-mechanical devices and inputs to the data recording portion of the apparatus are mediated by the digital logic system. The data which were recorded on paper tape were response correctness, time and number, filter wheel positions which determined the display luminances and grating orientation.

CALIBRATION

The luminances of the adapting and display fields were calculated from the spectral irradiances measured with an EG&G model 580/585 spectroradiometer. The spectroradiometer was positioned at the ocular of the optical system and the irradiances of the fields were measured at 10 nanometer intervals between 350 and 750 nanometers. The illuminances at the spectroradiometer were calcualted using the ICI Standard Observer luminosity data, and the luminances of the last lens of the ocular were calculated for the two fields. The maximum luminance of the display field was 4.11 log millilamberts. The peak luminance of the adapting field was 8.58 log Trolands.

Five adapting field durations were used in the experiment. The durations were controlled by the speed of rotation of the rotating mirror shutter. The trigger for the flash lamp was sychronized with the position of the mirror so that for four of the five durations, the flash presented to the observer was chopped from the flat portion of the flash lamp emission. The fifth duration was the unshuttered flash lamp emission. Each flash was monitored by displaying the light from the flash lamp before and after the rotating mirror shutter on a Tektronix 564 storage oscilloscope. The photodetector for the "before" monitor is shown at D_1 and for the "after" monitor is shown at D_2 in Figure 1. A typical trace is shown in Figure 4. The D_2 photodetector output was also displayed on a Hewlett-Packard 141B storage oscilloscope and the duration of each flash presented to the observer was measured. The data for any trial on which the duration deviated from the desired duration by more than ± 1.5% were discarded. The durations of all flashes were measured at one-half peak amplitude. A typical oscilloscope trace for a one millisecond duration flash is shown in Figure 5.

Neutral density filters were used to control the luminances of both the display and adapting fields. All filters were calibrated in the groups as they were constituted to provide field luminances with a Macbeth Illuminometer and on a Perkin-Elmer Spectrophotometer. The densities of the display filters and the display luminances are shown in Table 1. Densities of the adapting field filters and the integrated adapting field luminances are shown in Table 2.

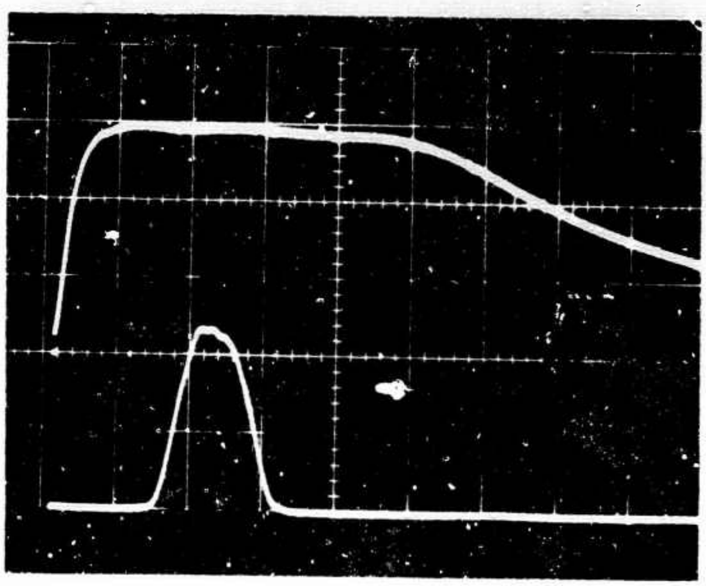

Figure 4. Flash CRO tracing of the lamp-shutter timing monitor.

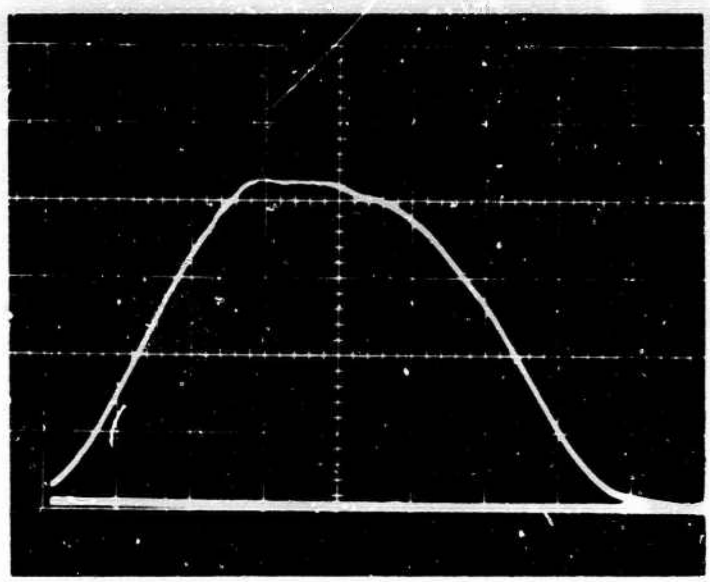

Figure 5. CRO tracing for a one millisecond duration flash.

TABLE 1

Display Filter Density and Luminance

Display	Filter Density	Luminance Log-mL
1	2.85	1.26
2	3.35	0.76
3	3.85	0.26
4	4.35	-0.24
5	4.85	-0.74

Table 2

Experimental Design

Adapting Flash Duration	Adapting Flash Integrated Luminance Log Troland-Sec.				
µSec.	0	4.58	4.98	5.28	5.58
0	A (control - no flash)				
100		B			
250		C (0.4)*	D		
500		E (0.7)	F (0.3)	G	
1000		H (1.0)	I (0.6)	J (0.3)	K
8500		L (1.9)	M (1.5)	N (1.23)	O (0.93)

Experimental Condition and Adapting Flash Filter Density

*Filter Density

PROCEDURE

Table 2 presents the fifteen conditions including the control condition, that were investigated. The four constant It flash conditions that were investigated were 4.58, 4.98, 5.28 and 5.58 log Troland-seconds. These four conditions were produced by presenting to the observer five flash durations filtered to the fourteen luminances, No flash was presented in the control condition. The 4.58 Log Troland-second adapting flash condition was produced by presenting flash durations of 100, 250, 500, 1000 and 8500 microseconds filtered with densities of 0, 0.4, 0.7, 1.0 and 1.9 respectively. The other It conditions were produced in like manner, as specified in Table 2. For all conditions, display gratings filtered to five luminances were presented. These display luminances are shown in Table 1.

Data were collected for one or two conditions during each experimental session. At the start of a session, the observer, O, was seated in a light-tight chamber and allowed to dark adapt for thirty minutes. A buzzer alerted the O at the completion of this adapting period. At the same time, a fixation cross was presented at the ocular. By means of a dental impression bite board, the O positioned himself at the ocular and fixated on the cross. When he was properly positioned and accommodated, he pressed the foot switch which was followed by the presentation of the flash and a display grating immediately afterward. The O was required to determine the horizontal or vertical orientation of the grating and to respond by pressing the proper button on the hand switch. As soon as a response was made, a shutter closed the display grating from the O's view. The filter condition was changed and a pre-set random coder determined the next display grating orientation. The display shutter reopened and the O was again presented with a display grating to which he responded. This sequence was repeated five times with each display dimmer than the preceding one. Following the fifth response, shutters closed from the O's view both the fixation cross and the display grating and the timing circuit started a five minute readaptation period. At the completion of the readaptation period, the buzzer sounded and the entire sequence of the flash presentation followed by five display targets was repeated. A completed experimental condition consisted of ten flash-target sequences for a total of fifty responses. To avoid fatigue all experimental sessions lasted a maximum of two hours including the thirty minute dark adaptation period. Complete data were collected for three observers.

RESULTS

The median response times for each observer in each experimental condition are shown in Table 3. The response timer was triggered by the leading edge of the adapting flash detector (D_2 in Figure 1) output.

Table 3

Median Response Time for Each Observer in Each Experimental Condition

Display Luminance (Log-mL)

	-0.74			-0.24			0.26			0.76			1.26		
	OBSERVER														
Condition	RAR	GTC	PEM	RAR	GTC	PEM	RAR	GTC	PEM	RAR	GTC	PEM	RAR	GTC	PEM
A	5.29	5.75	5.31	4.00	4.26	3.77	2.77	2.92	2.67	1.60	1.67	1.52	0.47	0.57	0.50
B	10.41	9.23	10.17	6.71	5.62	6.30	3.57	3.54	4.62	2.40	2.31	3.45	1.18	1.10	1.41
C	9.76	7.69	10.00	5.14	5.12	5.61	3.56	3.53	3.82	2.39	2.20	2.60	1.23	1.05	1.44
D	11.83	11.22	11.14	7.31	5.91	6.61	4.72	4.18	4.33	3.38	2.85	3.15	2.13	1.62	1.90
E	8.71	8.29	9.67	4.97	5.17	5.42	3.46	3.45	3.77	2.25	2.20	2.57	1.13	1.07	1.36
F	14.47	13.05	12.14	7.48	6.09	6.59	4.11	4.39	4.65	2.90	2.98	3.46	1.72	1.74	2.23
G	17.28	15.77	13.32	8.54	7.74	7.97	5.06	4.91	5.31	3.47	3.62	4.16	2.29	2.34	2.99
H	12.52	7.74	11.90	5.96	5.24	6.17	3.55	3.65	4.50	2.27	2.35	2.94	1.12	1.15	1.41
I	14.41	11.71	11.76	8.48	5.90	6.05*	4.35	4.26	4.06	2.76	2.96	2.83	1.65	1.66	1.66
J	18.57	16.49	15.55	10.19	7.19	7.57	5.28	4.86	5.07	3.95	3.49	3.90	2.71	2.30	2.75
K	26.04	21.21	24.11	12.66	10.98	12.31	7.62	6.82	7.85	6.09	5.14	6.27	4.86	3.85	5.13
L	9.24	8.84	10.00	5.03	4.96	5.58	3.51	3.49	3.86	2.34	2.30	2.59	1.12	1.16	1.28
M	12.96	10.47	10.46	6.57	5.89	6.40	4.32	4.35	4.47	3.05	2.97	3.28	1.86	1.79	1.96
N	16.21	15.80	14.85	9.87	7.68	10.04	5.76	5.30	7.36	4.49	4.02	6.02	3.24	3.13	4.76
O	26.21	18.63	22.70	12.65	8.70	10.75	7.33	6.37	8.22	5.92	4.87	6.53	4.65	3.53	5.35

The response times, therefore, are measured from the start of the adapting flash.

The median response times for all observers in each adapting flash integrated luminance condition and to each display luminance are presented graphically in Figures 6 through 9 to show response time as a function of adapting flash duration. These data show that the response times to each display level are longer in every adapting flash condition than in the control condition in which no flash was presented, that the response times are longer when the total integrated flash luminance is high, and that there is no obvious consistent difference in response time as a function of adapting flash duration when the total integrated luminance of the adapting flash is constant.

In a further attempt to assess experimental effects, an Analysis of Variance was performed on the data for conditions E through J and L through N. The B, C, D, K, and O conditions were not included because of the imbalance in the overall design when the 100 and 250 microsecond durations and the 5.58 log Troland-second integrated luminance were included. The Analysis of Variance Summary Table is presented in Table 4. This analysis supports the relationships shown in Figures 6 through 9. The response time differences as a function of flash integrated luminance and target luminance are significant at the 0.01 level. There is no significant difference in response times as a function of flash duration. The only significant effect which is not obvious in the graphic presentations in Figures 6 through 9 is the two-way interaction involving flash integrated luminance and flash duration. That interaction is significant at the 0.05 level. The data for the two dimmest targets have been plotted in Figures 10 and 11 to show response time as a function of adapting flash duration with It constant. The points connected by solid lines represent data included in the Analysis of Variance while those connected by broken lines were not included in the Analysis. In every case but one, the response time is longer following the one millisecond flash than following the 8.5 millisecond flash, and then is shorter for one or more of the shorter duration flashes. This irregular interaction may account for the absence of any direct flash duration effect, and may also be the factor which led to earlier interpretations of data as indicating a failure of reciprocity in adapting effects of high intensity, short duration flashes of light (2, 3).

DISCUSSION

The data reported above indicate that while a strict reciprocity relationship between adapting effects of short duration flashes may not apply, the interaction between the total luminance and the duration of a flash is a complicated one. The overall response differences, regardless of direction, for different flash durations is small. The combination of these two factors, complex It-t interaction and small duration effects, indicates that protection device closure times should be deter-

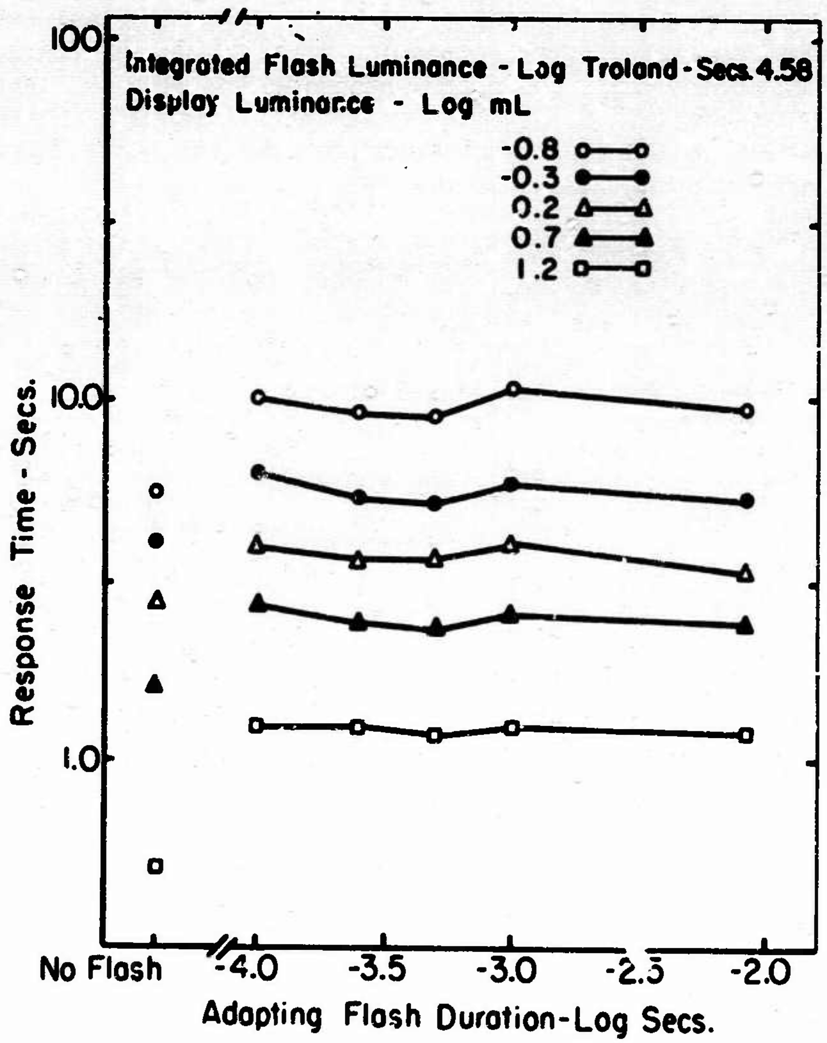

Figure 6. Response time as a function of adapting flash duration for the 4.58 log Troland-second integrated flash luminance.

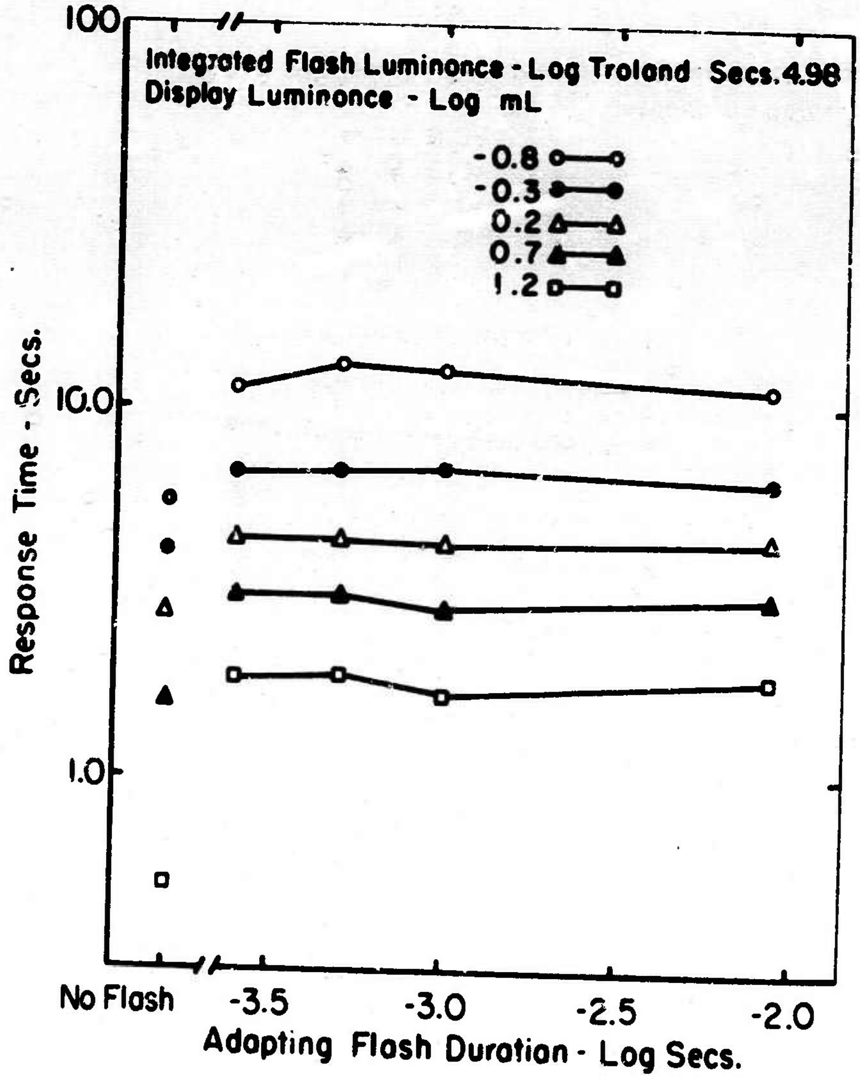

Figure 7. Response time as a function of adapting flash duration for the 4.98 log Troland-second integrated flash luminance.

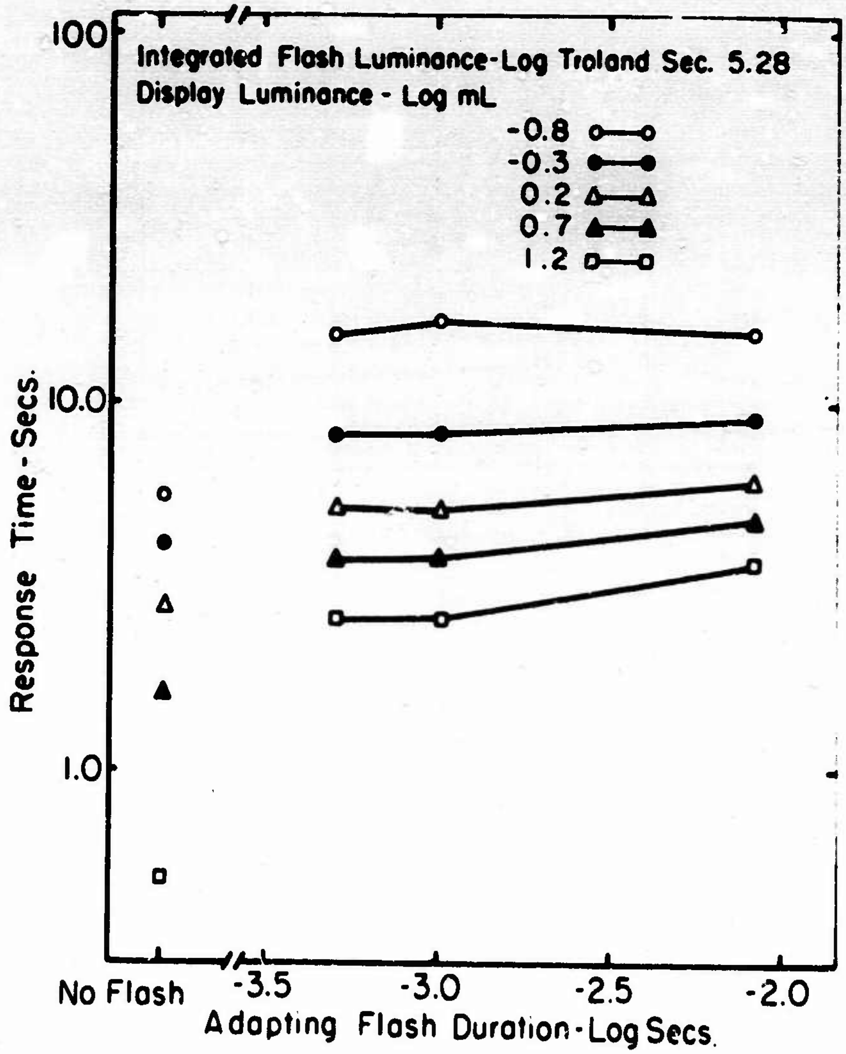

Figure 8. Response time as a function of adapting flash duration for the 5.28 log Troland-second integrated flash luminance.

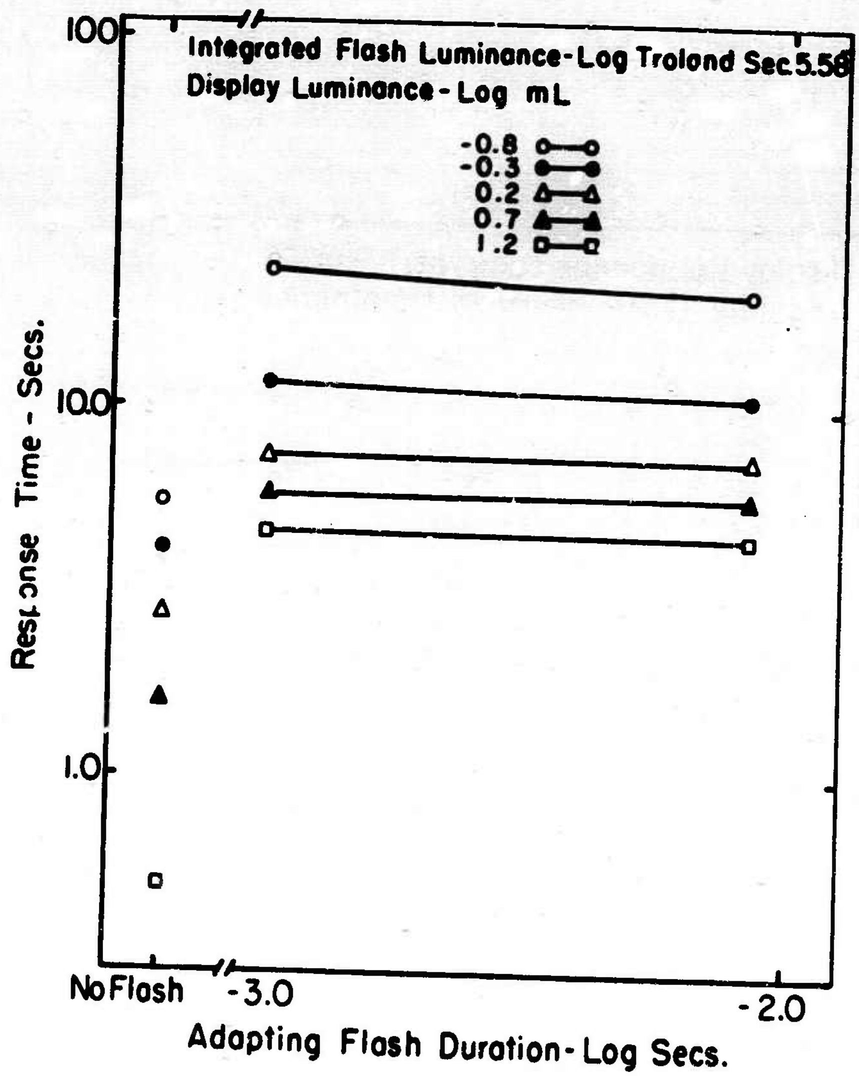

Figure 9. Response time as a function of adapting flash duration for the 5.58 log Troland-second integrated flash luminance.

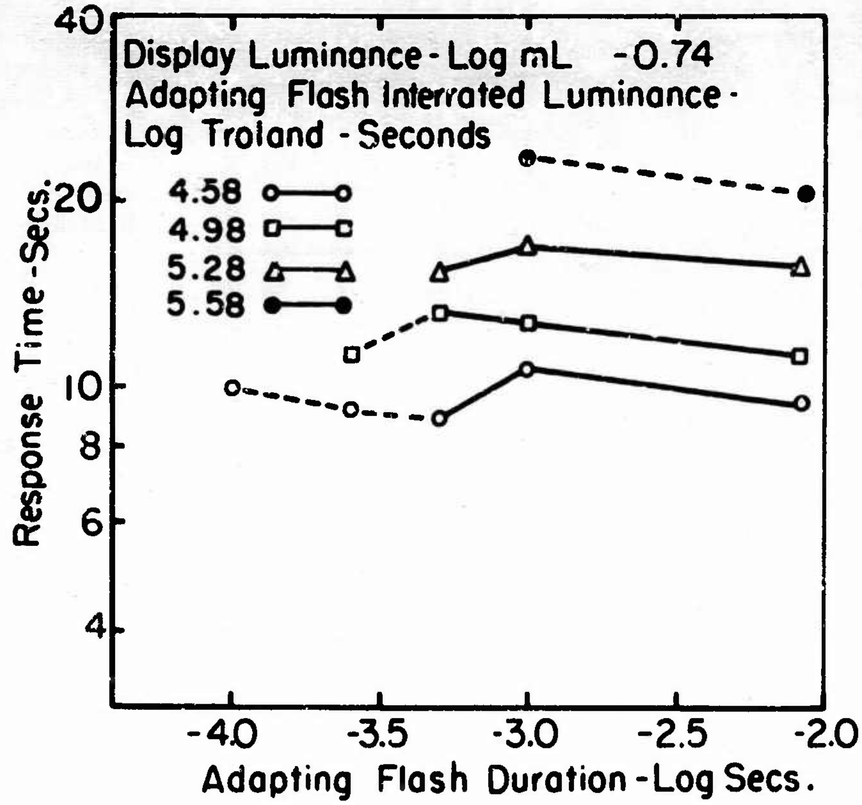

Figure 10. Response time as a function of adapting flash duration for the -0.74 display luminance. Broken lines connect points not included in the Analysis of Variance computations.

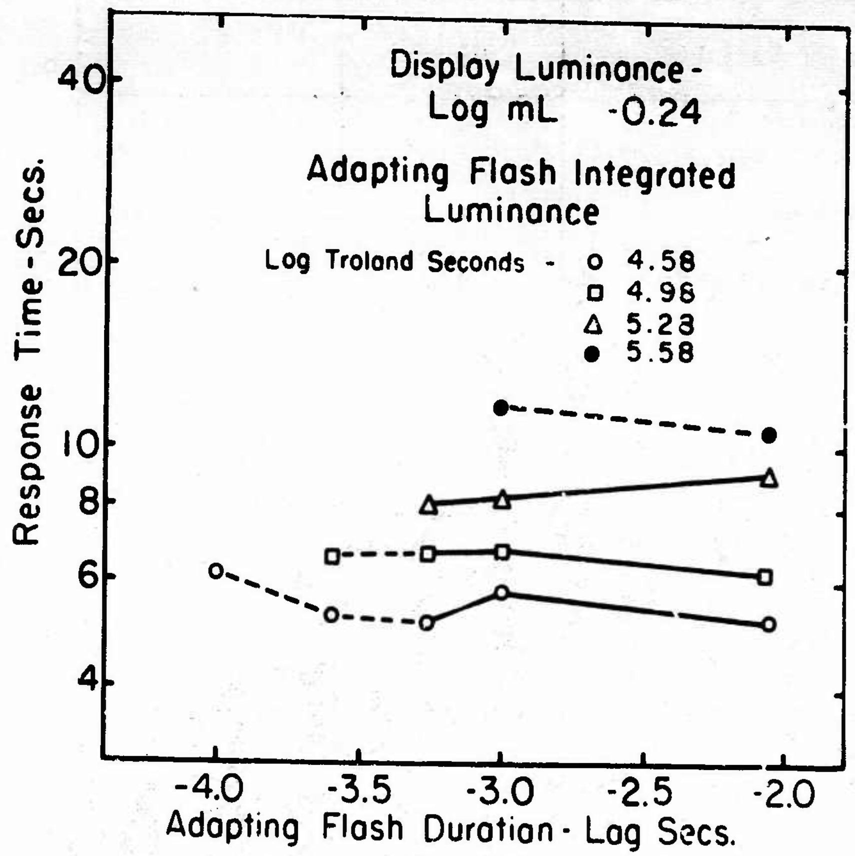

Figure 11. Response time as a function of adapting flash duration for the -0.24 display luminance. Broken lines connect points not included in the Analysis of Variance computations.

Table 4

Analysis of Variance Summary Table

Source of Variance	df	F
Flash It (It)	2	158.48 **
Target (T)	4	736.03 **
Flash Duration (D)	2	0.83
It x D	4	3.15 *
T x D	8	1.49
It x T	8	14 .52 **
It x D x T	16	0 .74
Error	90	

** $P < 0.01$

* $P < 0.05$

mined on a basis other than a general principal regarding the effects of faster closure times. From a practical point of view, planners must consider the characteristics of the critical flash source combined with the proposed characteristics of a protective device and determine the efficacy of the proposed device characteristics on the basis of the effect of the potential flash to which a device wearer will be exposed.

From a theoretical point of view, the results reported here raise some interesting questions regarding the effects of very short supra-threshold flashes of light on the eyes. The existence of complex relationships between response time and flash duration is supported by electrophysiological data from this laboratory (4). The electrophysiological response to adapting flashes identical to some of the flashes used in the present experiment also showed some ambiguity as far as interpretation in light of the Bunsen-Roscoe or Block's Laws is concerned. In the electrophysiological results, both the ERG a-and b-wave amplitudes were constant for constant Its, but the latency of the b-wave decreased markedly for shorter durations. One question raised in the interpretation of the ERG data (4) is applicable to the present results; that is the question regarding the relatively low total energy levels at short durations.

The psychophysical data reported here and the electrophysiological data of Rosenblum (4) lend credence to the conclusions that a strict reciprocity relationship does not apply at very short adapting flash durations, and that the relationship is a complicated one.

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